

Evaluation of Special Sensor Microwave / Imager Sea-Ice Products

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Abstract

Existing SSM/I algorithms are imperfect at mapping total and partial ice concentrations. This paper reviews recent findings based on comparisons of sea-ice products against other satellite data and U.S. National Ice Center (NIC) ice charts.

INTRODUCTION

Sea-ice products from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave / Imager (SSM/I) are continually adding to the already long time series of passive microwave observations of conditions in the polar regions. This time series has the potential to yield information on the high latitude climate signal. Furthermore, SSM/I data has become a routine set of data for use in the production of operational ice charts [1] and is the primary source of information on ice conditions that is used to initialize the U.S. operational ice-ocean model, PIPS [2]. Given the range of important scientific and operational analysis that depends on these data, it is imperative to have a complete appreciation of the weaknesses and strengths of the SSM/I-derived sea-ice products. The study reviewed here was used as the basis for recommending updates to the operational SSM/I sea-ice products generated by the U.S. Fleet Numerical Modeling and Oceanography Center (FNMOC).

CURRENT OPERATIONAL SEA-ICE PRODUCT

The current operational sea-ice product generated by FNMOC for NIC is the CAL/VAL algorithm [3]. This was designed in the early 1990s as a modified version of the AES-York algorithm [4]. It was designed in particular to provide an accurate location for the ice edge and so uses the high spatial resolution 37 GHz channel in areas of low ice concentration. Elsewhere, it used a combination of 19V and 37V channels with various consistency checks to enable filtering for weather and rough ocean conditions.

In Summer, 1998, following a request from NIC, the NASA Team algorithm was implemented at FNMOC and the two products provided in parallel. The NASA Team

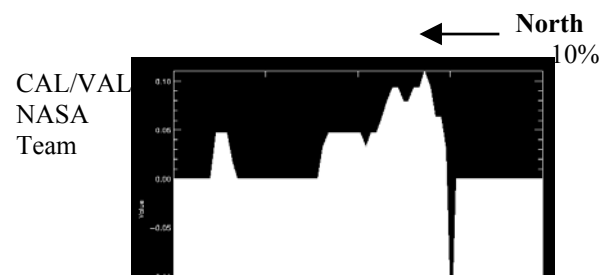
algorithm was implemented on the basis of its popularity within the scientific community and the fact that it has been relatively well evaluated, compared to most other SSM/I ice concentration algorithms [5]. NIC agreed to undertake an evaluation of these two algorithms as a precursor to recommending how FNMOC and NIC should proceed in the development and use of its operational sea-ice product. To broaden the evaluation, NIC implemented internally the Bootstrap algorithm [6] and NASA Team algorithm for thin ice [7], the latter algorithm being designed to work in areas where there is no multi-year ice.

COMPARATIVE EVALUATION OF SSM/I ICE CONCENTRATION ALGORITHMS

Table 1 shows how differences between estimates of ice concentration from different algorithms can be extremely large. The table gives examples of differences between the CAL/VAL and NASA Team algorithms for regions in the northern and southern hemispheres, on the 9th December 1998.

Region (9 Dec. 1998)	Season	Mean Conc. Diff. (%)	R.m.s. Conc. Diff. (%)	Mean 0% Conc. edge position diff. (km)
Central Arctic	W	2.6	3.34	-71.0
E. Greenland	W	8.8	5.4	-23.0
Baffin Bay	W	13.5	6.2	-23.0
Sea of Okhotsk	W	29.0	8.9	-44.0
Bellinghausen	S	14.5	5.3	-24.0
Weddell Sea	S	15.3	6.2	-21.0

Table 1. Differences between the CAL/VAL and NASA Team algorithm ice concentrations by region and season. A “+” sign indicates that the CAL/VAL algorithm predicts more ice than the NASA Team algorithm. “W” indicates winter and “S” indicates summer.



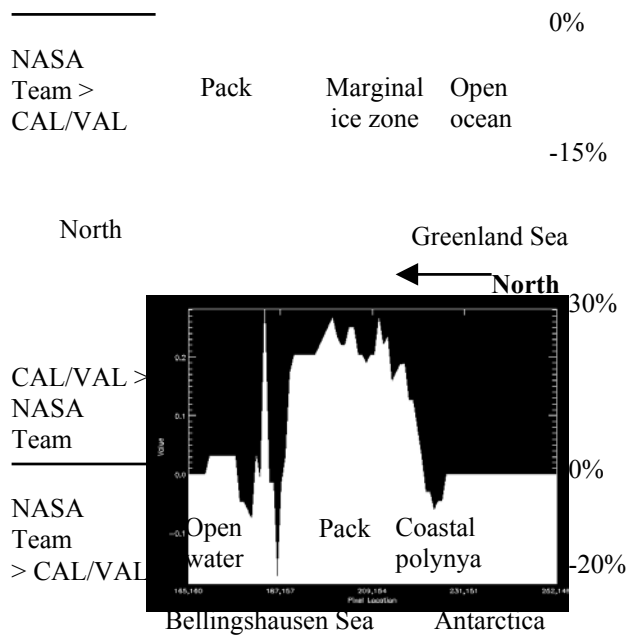


Figure 1. One-dimensional profiles showing CAL/VAL – NASA Team algorithm differences (in % ice concentration) in the Arctic (top figure) and Antarctic (bottom figure).

Figure 1 shows how the difference between the two algorithms varies from the interior of the pack towards the edge. It can be seen that the differences are substantial and vary systematically with location, being greatest in the marginal ice zone in the Arctic during winter and in the interior of the pack in the Antarctic during summer. The CAL/VAL algorithm shows significantly more ice than the NASA Team algorithm over the vast majority of both regions, often >10% in the Arctic and >20% in the Antarctic. However, there is a narrow but significant region at the ice margin of a few tens of km width in which the NASA Team algorithm shows more ice than the CAL/VAL algorithm and this is season and region independent.

The area of most significant difference in the north is found in the Sea of Okhotsk on 9 December 1998. An NIC ice chart is available for that time which was analyzed using relatively cloud-free DMSP Operational Line-Scan System (OLS) data and shows a high proportion of new and young ice. Figure 2 compares the ice chart with predictions from different algorithms.

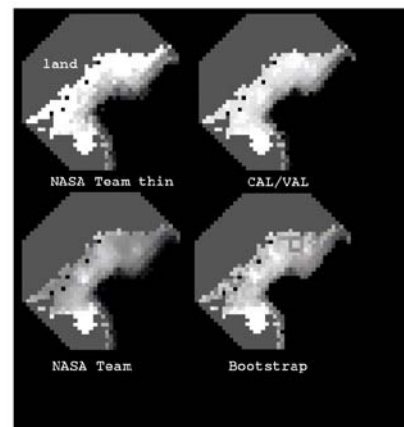
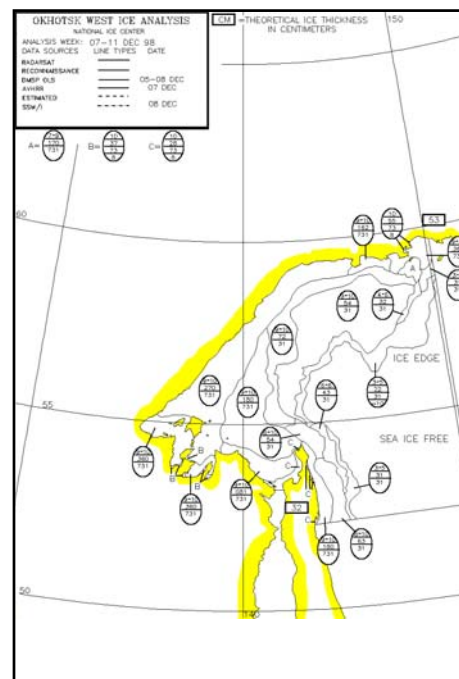


Figure 2. Comparison of algorithms with the NIC ice chart for the Sea of Okhotsk, 9 December 1998. White indicates 100% ice concentration and black 0% ice concentration.

INTERPRETATION OF DIFFERENCES

The differences recorded here are significant for any application. The differences can be explained by a number of factors.

Ice edge position difference

The difference in ice edge position found for the NASA Team and CAL/VAL algorithms is probably related to the different spatial resolutions of the 37 GHz and 19 GHz channels. The CAL/VAL algorithm makes use of the

37GHz channels at the ice margin and so has better spatial resolution than the NASA Team algorithm. The difference in the effective field of views of these two frequencies is between 14 and 39 km, depending on direction relative to the ground track [3] and this is consistent with the differences in ice edge position that are observed. This explanation is consistent with the fact that the ice edge difference appears to be independent of season and hemisphere.

Ice type sensitivities

Comparison of the algorithm predictions in Figure 2 suggests that there is severe under-estimation of new and/or young ice types by the NASA Team algorithm. The Bootstrap algorithm also under-predicts ice concentration as does, to a lesser extent, the CAL/VAL algorithm. The NASA Team algorithm modified for thin ice appears to work reasonably well in this area. Concentrations are close to those suggested by the ice chart and in fact, the Sea of Okhotsk is a prime candidate for use of the NASA Team algorithm modified for thin ice. The differing sensitivities of the algorithms to thin ice types are illustrated further in Figure 3, which shows ice concentrations calculated using controlled observations of different ice types (the "correct" concentration is 0% for open water and 100% for ice). It can be seen that there is a wide range of sensitivities of the algorithms to different types of thin ice.

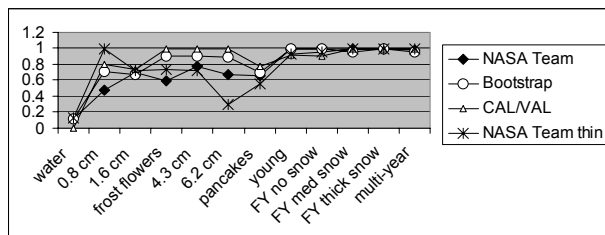


Figure 3. Ice concentrations predicted by different algorithms from controlled observations of different surface types. Observations recorded by Grenfell [8], Wensnehan et al. [9] and the 1998 North Water experiment.

The pattern of differences in ice concentrations shown in Figure 2 can be explained largely in terms of different algorithm sensitivities to thin ice types. Mapping of multi-year ice using SSM/I is also subject to difficulties, possibly related to flooding of the surface and/or thick snow cover masking the underlying "fresh" ice.

CONCLUSIONS AND RECOMMENDATIONS

This study has shown that major differences in ice concentration result from the use of different algorithms. The differences are sufficiently large to justify a different

approach to the use of SSM/I in operational mapping of sea-ice, which should be based on data fusion or data assimilation techniques. Such an approach is demonstrated in [1].

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REFERENCES

- [1] K.C. Partington, *Data fusion for use of passive microwave data in operational sea-ice monitoring*, this proceedings.
- [2] A. Cheng and R. Preller, *The development of an ice-ocean coupled model in the northern hemisphere*, Naval Research Laboratory technical report NRL/FR/7322-95-9637, 1996.
- [3] J.R. Hollinger, R. Lo, G. Poe, R. Savage and J. Pierce, *Special Sensor Microwave / Imager Calibration/Validation*, Final Report, Washington DC: Naval Research Laboratory, pp. 10-1 to 10-20, 1991.
- [4] R. Ramseier, I.G. Rubinstein and A.F. Davies, *Operational evaluation of Special Sensor Microwave / Imager by the Atmospheric Environment Service*, report from the Centre for Research in Experimental Space Science, York University, North York, Ontario, Canada, 1988.
- [5] D. Cavalieri, P. Gloersen, P. and W.J. Campbell, *Determination of sea-ice parameters with the NIMBUS 7 SMMR*, Jnl. Geophys. Res., vol. 89, no. D4, pp. 5355-5369, 1984.
- [6] J. Comiso, *Characteristics of Arctic winter sea-ice from satellite passive microwave and infrared observations*, Jnl. Geophys. Res., vol. 89, no. C1, pp. 975-994, 1986.
- [7] D. Cavalieri, *A microwave technique for mapping thin sea-ice*, Jnl. Geophys. Res., vol. 99, no. C6, pp. 12,561-12,572, 1994.
- [8] T.C. Grenfell, *Surface microwave passive microwave observations of sea-ice in the Bering and Greenland seas*, IEEE Trans. Geosci. Rem. Sens., vol. GE-24, no. 3, pp. 378-382, 1986.
- [9] M. Wensnehan, G.A. Maykut, T.C. Grenfell and D.P. Winebrenner, *Passive microwave remote sensing of thin sea ice using Principal Component Analysis*, J. Geophys. Res., vol. 98, no. C7, pp. 12,453-12,468, 1993.